472

VOLUME 80 SEPARATE No. 472

PROCEEDINGS

AMERICAN SOCIETY OF CIVIL ENGINEERS

AUGUST, 1954

INFILTRATION GALLERIES

by Ralph Stone, A.M. ASCE

SANITARY ENGINEERING DIVISION

{Discussion open until December 1, 1954}

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Printed in the United States of America

Headquarters of the Society
33 W. 39th St.
New York 18, N. Y.

PRICE $0.50 PER COPY

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This paper was published at 1745 S. State Street, Ann Arbor, Mich., by the American Society of Civil Engineers. Editorial and General Offices are at 33 West Thirty-ninth Street, New York 18, N. Y.

INFILTRATION GALLERIES

Ralph Stone,[1] A.M. ASCE

SYNOPSIS

The various factors involved in infiltration gallery construction and operation are reviewed; they include: ground water hydrology, water quality and treatment, aquifer permeability, economics, and hydraulics.

The experience of numerous communities with infiltration gallery water works are described.

Galleries can provide a well purified, dependable, low cost water supply.

INTRODUCTION

Infiltration galleries are horizontal type permeable conduits that intercept and collect ground water by gravity flow for a water supply source. Among the first man made water works were the Persian "Kanats". Extensive underground galleries are still employed for the water supply of Teheran. Unfortunately these infiltration galleries were often used for direct sewage disposal as well as for a water source. According to Butler(1), the Tunnel of Negoub was constructed in 800 B.C. Through the centuries, including the present day, there are many water systems that have successfully operated infiltration galleries for part of their water supply. Cities as large as Des Moines, Iowa, New York City, N.Y., Los Angeles, California, as well as many other foreign communities and smaller cities have economically exploited this means of simple water treatment and supply. (See Table 1.)

Limitation of Infiltration Galleries

Relatively little recent basic engineering information is found in the literature concerning infiltration galleries. Perhaps for this reason, few galleries are built and there are many failures in design, construction and operation. A survey of engineering experience with infiltration galleries has been completed and the results of field studies, correspondence, and a literature review are herewith summarized.

Limitations of infiltration gallery use include (1) A shallow aquifer is required for low cost construction. The necessity of dewatering during installation of the gallery may result in exhorbitant construction costs which, unless fully planned, result in an uneconomical installation.

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Secondly, a plentiful recharge of ground water must be available if the shallow infiltration gallery is to continue to produce at a high rate. The source of recharge of infiltration gallery aquifers include (1) Direct spreading of imported water into pervious surface spreading basins, (2) Recharge of a granular stratum underlying a water body, or (3) A large artesian aquifer continuously supplied by distant sources.

A third limitation of infiltration galleries is that in order to be successful they should collect water that is satisfactory in chemical quality. Except for certain localized pollution, the physical and bacteriological water quality of a properly constructed and operated infiltration gallery should be excellent.

Advantages of Galleries

The advantages of utilizing an infiltration gallery for a water source should be evaluated for each particular installation. However, following a competent hydrological study in which it has been determined that adequate ground water conditions exist, infiltration galleries may be the economical and superior water works. Particularly for a small water system, a gallery is a relatively low cost installation requiring minimum operating expense. In comparison, the cost of constructing a chemical treatment plant with conventional high rate filtration should be greater than that required for building infiltration galleries. The cost of shallow gallery construction ($10 to $50+ per horizontal ft.) should be not more than twice that for installation of a comparable shallow well field.[2] However, the long life, and low operating expense may result in the galleries being even more economical and satisfactory than the shallow well supply. Besides the first cost, the conventional water filtration plant bears the expense of (1) head loss and pumping (2) flocculating and treatment chemicals (3) washing of filters (4) constant full time operation requiring highly trained personnel and (5) repairs and maintenance of pumps and other equipment. The infiltration galleries are a water works that can be operated by part time personnel that have little technical training. In certain backward areas, galleries may be particularly desirable as a source of water supply because limited chemical supplies, mechanical equipment, financial and technical resources are available for operation of a conventional filtration works.

The filtration of raw water through pervious soil along with the long time storage within an underground aquifer provides for natural removal of suspended solids, turbidity, color, as well as for the purification of the raw water so as to eliminate organic colloidal matter and pathogenic pollutants.

Field tests at Whittier and Azusa, California [3] have demonstrated that a sparkling clear potable effluent can be produced from partially treated sewage discharged into spreading basins and infiltrated through 3 to 7 feet depth of soil. Greenberg and Gotaas [4] have found that a water meeting drinking water standards was collected after polluted water had infiltrated through soil. Others [5] have reviewed the effectiveness of soil percolation in removing pathogens and organic matter from polluted waste water. The efficiency of slow sand filters in water purification is well established. The infiltration gallery through low

percolation rates enables a high grade biological treatment of water where more rapid chemical and mechanical process may be less feasible.

Infiltration galleries as contrasted to wells should employ gravity inflow to intercept the ground water. In comparison, conventional shallow wells waste power to maintain a negative pressure head for drawdown and pump only part of the ground water flow for the well suction field. Four feet or more of equivalent water head may be used in pulling air from the pervious stratum to maintain the continuous vacuum for pumping water.

Galleries can be used by cities located adjacent to an ocean or other saline water bodies for a sodium source to regenerate zeolite filter water softeners. The city of Ventura, California, employs such a gallery for collecting a clean salt water to regenerate their municipal water treatment plant zeolite filters.

Infiltration galleries can also be used to tap water stored in underground natural storage basins. The City of Santa Barbara, California in past years has employed a 2000 ft. long 8 in. diameter horizontal gallery operated by a control valve to drain the infiltrated runoff water stored within a natural aquifer. This water was used as an emergency supply during the hot, dry, summer period.

Infiltration galleries may be directly applied to the treatment and reclamation of organically polluted waste waters. For example, the City of Amsterdam, Netherlands, plans to recharge 7 to 14 million gallons per day of organically polluted Rhine River water within existing sand dune aquifers which would then percolate and store a purified water effluent tapped by galleries and surface drains. Frankfort, Germany is another municipality that has thus reclaimed a badly polluted pathogenic and organic waste loaded raw water. The travel of the polluted water through linear or vertical distances varying from 10 to 1600 ft. of porous sand and gravel enables the action of time, aerobic zoogleal organisms as well as other physical and chemical factors to purify the contaminated influent. The infiltrated raw waste water loses its original identity and blends with the existing ground water so that aesthetic opposition to reuse of waste water is minimized.

Experience with Infiltration Galleries

Among the types of aquifers developed for infiltration galleries include springs, rock fissures, shallow ground water stratums and locations adjacent to a stream, lake or other water recharge source.

Infiltration galleries can be built to develop a maximum supply of water from a spring. The construction of a collection pipe and clear well to protect the spring water supply from pollution is a common and desirable practice. Particularly in mountainous areas, infiltration galleries can be employed as collection works to discharge a sanitary potable water from the highland springs into a gravity transmission pipe line leading to a community located in the mountain valley.

Rock aquifers recharged through limestone or volcanic fissures may supply large quantities of water. In Hawaii the volcanic "pahoehoe" and "aa" volcanic formations collect the surface waters that infiltrate

from the mountainside through rock fissures. The galleries skim off fresh water which is gravimetrically situated above a saline ground water. Because of the controlled drawdown of the collection tunnel, the saline waters are kept out of the fresh water supply and salt water intrusion is prevented. In Florida, the rock fissures throughout the ocalla limestone aquifer may be considered as a natural gallery type water supply source for many of the west and central Florida communities and industries. In addition to the aquifer acting as a major water resource, waste effluents have in the past been disposed through drainage wells directly into the limestone and as a result the aquifer has been subject to localized pollution.

The construction of galleries as collection interceptors for rock aquifers may or may not involve the presence of sand or gravel as a percolating medium prior to infiltration into the gallery. Where a shallow permeable aquifer is recharged by a large ground water flow, obviously the infiltration gallery will continuously discharge large quantities of water. Communities located near river or valley bottoms containing artesian aquifers have successfully developed this type of infiltration gallery. More commonly however, galleries are constructed directly adjacent to a river or other water source and receive much of their recharge from the surface water body. Many galleries in the United States are constructed in river beds and include communities along the Ohio River, Mississippi River, and other streams. (See Table 1). It should be noted that the river head waters where there is a relatively high velocity of flow have proven to be the most satisfactory locations. Because: (1) The high flow velocities carry away the fine sediment which would reduce the permeability of an aquifer; (2) The head waters of streams are a relatively pure and desirable water source; (3) The coarse porous sand and gravel enable rapid recharge; and (4) good collection rates generally are possible.

At Des Moines, Iowa, when there is a limited water flow, the city's infiltration gallery is not only recharged indirectly from the river source but by means of spreading basins located directly above the gallery.

Types of Interceptors

Clear distinction can be made between the infiltration gallery located directly within a pervious aquifer and which depends only upon gravity drawdown to collect the ground water flow and a second type of gallery which employs an underground dam, that is either a natural or man made structure. The underground dam may be built of impervious material such as rock, clay or concrete. The dam assures that most of the existing ground water except for the dam overflow will be stored in the aquifer system, and eventually collected by the infiltration gallery. At Harrisonburg, Virginia, the infiltration gallery is located within a sand and gravel stratum underlain by an impermeable Pocono sandstone bedrock. A concrete underground dam is constructed across the stream and the underground water is intercepted by a gallery that has been operating successfully many years. Circleville, Ohio and Los Angeles, California are examples of municipalities that operate galleries within a river bottom without installing underground dams.

Depth of Aquifers

Many galleries are built at what would be considered a shallow depth for well supplies. In fact, infiltration galleries appear to operate satisfactorily with 15 ft. of permeable stratum as a cover. The range in soil depth appears to be between 2 ft. and 919 ft. (See Table 1) above the gallery pipe. Reasons for use of shallow aquifers include: (1) Surface construction costs are proportional to the depth of trench excavation and (2) Desirable water quality may be achieved with shallow galleries. In the case of shallow wells, the pump suction may assist in allowing surface pollution to travel along the fissure provided by the outside well casing and thus to enter the pumped water. With an infiltration gallery this cross connection should not exist, since the ground water is not collected under vacuum and the low gravity flow rates allow the surface water to be purified prior to collection. Deep galleries located in sand aquifers tapped by tunnelling into mountain sides should be less susceptible to surface water pollution.

Infiltration Galleries Construction Details

Galleries can be dewatered during construction by use of sheet piling or well points while excavating and installing the collection system. At locations where artificial recharging is used to maintain the water table, the gallery in effect operates in a manner similar to a slow sand filter and then dewatering may not be required. It is desirable to construct the gallery during the relatively dry season of the year so that minimum surface water or ground water flooding can occur. The cost of construction of infiltration galleries, it has been previously noted, may be in the range of approximately twice the cost of a shallow well system. However, modern construction methods including wet, in place installation, using experience obtained with building outfall sewers and tunnels, can reduce this cost. The operating expense of infiltration galleries should be less than for a well system since hydraulic and construction features should enable a long life requiring minimum maintenance or repairs. Vitrified clay, brick, concrete, reinforced concrete and cast iron have proven to be successful gallery construction material. Where wood, steel or impermanent construction materials are used, the gallery may fail after a short life. (See Table 1)

On the contrary, well construction galleries have been utilized in such locations as Los Angeles, California and Des Moines, Iowa for over 40 years without reported reduction in the collection rates. The infiltration gallery pipe should be perforated and connected by open joints so as to allow low entrance velocities for the collected water. High entrance velocities into the gallery may cause the washing of fines into the inlet openings, cause plugging and thus reduce infiltration rates and result in the abandonment of the gallery. The gallery diameter size to be used should be (1) large enough for inspection and maintenance of the gallery and (2) be designed to hydraulically carry the total expected infiltration water flow at desired velocities. Where flow velocities are less than 2 ft. per second, sand traps and cleanouts should be built for removal of grit. With modern pipe cleaning devices it may not be necessary to use large pipe sections so that a man can physically enter the

gallery for repair and maintenance purposes. Back washing with water, acid, or chlorine solutions has been tried at some locations. However, an expensive backwash is not required for routine operation of most galleries. (See Tables 1 and 2). The gallery is often laid within a graded gravel and sand cradle and back filled with the same material. Manholes should be located each 250 to 600 feet distance so that inspection and maintenance of the gallery can be economically performed. The infiltrated water flows through the gallery to the collection sump. Turbine type pumps operated by automatic switches can then discharge the water into the distribution system. Normally chlorination is the only additional treatment supplied.

Quantity of Water Produced

Most successful infiltration galleries are located in porous aquifers consisting of sand-gravel mixtures or rock fissures. A properly located gallery within a porous sand and gravel aquifer should average infiltration rates of about 1 million gallons a day per 1000 ft. of interceptor length (See Table 1). Galleries that are located in rock fissures or coarse aquifers that are rapidly recharged by fast flowing ground water, may supply higher infiltration rates. Fine sands i.e. aquifers with reduced porosity can be expected to supply less than 1 million gallons a day per 1000 ft. of collector length.

The quantity of yield of an infiltration gallery may be estimated by simple calculation as follows:[6]

(1) Quantity = Q = velocity of intercepted ground water flow x area of cross section of intercepted ground water stratum x average porosity of the aquifer = v a p. Units are in ft. and day.

(2) If V = constant, x slope in ft. per mile = ks.

(3) Then Q = ksap

If kp = permeability coefficient = K

(4) Then Q = Ksa

Field tests should be performed to accurately estimate gallery yields by determining: (a) the flow direction of an aquifer and (b) how much the gallery collector will intercept of the total possible ground water flow and (c) the velocity of flow cross section area and porosity (equation 1) of the aquifer.

Tables (6) and (7) can be used for various permeable media to obtain a preliminary and less accurate estimate of the permeability coefficient (equation 4) for calculation of an estimated yield of a gallery. Muskat and Wycoff [8] carefully covers the theory of liquid flow through porous media.

Information on gallery yields ennumerated in Table 1, indicates that except for fissured rocks, the maximum dependable yield for most sand and gravel aquifers is less than might be expected from theoretical estimates.

Failures

Infiltration gallery failures can be reviewed as warnings to assist in successful applications. These failures can be summarized briefly as follows:

a. The gallery was located in a water table which during natural dry periods or subsequent man made influences resulted in a lowered water table leaving the collection works high and dry.

b. The infiltration gallery was improperly located in a poor aquifer with a limited volume of water recharge. After the initial water was obtained from the local lens, the gallery did not collect an adequate quantity of water. Stratum containing clay or organic matter as well as a sand stratum restricted by hard pans may prove unsatisfactory as aquifers.

c. Permeability reduction of aquifers has resulted in the failure of certain collection works. Permeability reduction can be caused by the precipitation of minerals with incrustation of the sand and pipe perforations and subsequent sealing of the gallery. Biological growths such as zoogleal bacteria may reduce the permeability so as to prevent effective infiltration. Sealing of three horizontal well screens by introduction of fine clay and other impervious turbidity resulted in the abandonment of horizontal wells at South Haven, Michigan in 1902. Insufficient perforation area in the gallery will provide high velocities of inflow and possible sealing. A low velocity of water infiltration, emergency backwash of the gallery, repair of damage to structures, and maintenance by periodic cleaning or chlorination are remedial actions that can be employed for redeveloping infiltration rates. The excavation and replacement of the sand and gravel surrounding a gallery is an expensive and generally unsatisfactory method of maintaining infiltration rates.

d. Many galleries have failed because of collapse of the wooden or other non-permanent type collection works. Obviously a strong stable construction material should be used to minimize structural deterioration by corrosion and other forces.

e. The pollution of infiltrated water by chemical wastes such as salt water from oil field brines or chlorophenols, nitrates, and other toxic chemical compounds may result in unsatisfactory water supply. Obviously the water source entering the aquifer should be of satisfactory chemical quality to meet drinking water standards. Pathogenes are removed by slow filtration through the aerobic porous media environment provided by the gallery. Gross pollution loads of organic wastes or cross connections may result in contamination of a shallow aquifer. However, bacteriological analyses of numerous samples collected in many infiltration galleries are reported to be of satisfactory pathogen free quality even when grossly polluted raw water sources recharge the aquifer. Public health authorities would not allow an infiltration gallery supply of unpotable water to operate.

f. The cause of failure of many galleries is that they were either improperly designed or under designed and hence not enough gallery was installed for the large quantity water supply desired.

SUMMARY AND CONCLUSIONS

1. Infiltration galleries can provide an economical and dependable water works.

2. Galleries can have the advantage of collecting a naturally purified water.

3. Galleries can be used for collection of water in shallow aquifers preventing salt water intrusion.

4. Galleries may supply 1 mgd per 1000 ft. of length. Permeability and recharge factors control the quantity of yield.

5. Details of gallery construction and operation are noted in the paper.

ACKNOWLEDGMENT

Full acknowledgment is made of the information generously supplied by many City Engineers, Water Works Superintendents, and other authorities concerning the construction and operation of infiltration galleries.

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TABLE I

INFILTRATION GALLERY SURVEY DATA SUMMARY

NO.	CITY	GALLERY				YIELD		SOURCE OF RECHARGE	NOTES:
		AQUIFER MEDIA	CROSS SECT.	LENGTH	DEPTH BELOW SURFACE	FOR TOTAL LENGTH	PER 1000'		
	Unit	--	Ft.	Ft.	Ft.	MGD	MGD	--	
1.	Amsterdam, Netherlands	Sand Dunes	-	Variable	-	18	-	Rain and Spread river water	Plan to recharge by spreading 7-14 MGD of filtered Rhine River water. 14.4 miles^2 catchment dune area, run-off is 605 million ft.^{3}/yr.
2.	Circleville, Ohio	Sand and Gravel	3	650	11-19	3	4.6	River	* (See footnote)
3.	Des Moines, Iowa	0.35-0.45 eff. size sand&gravel	4	18,500	Approx. 10-25		0.6-1.4	River	1 MGD for each 1300 ft. 10-15' below water table. Reinforced concrete rings of 2' length used.
4.	Eureka, Calif.	-	-	-	-	-	-	-	Abandoned (wooden cribbing).
5.	Fort Dodge, Iowa	-	-	-	-	-	-	-	Abandoned 40 years ago.
6.	Gallipolis, Ohio	-	-	-	-	-	-	-	Abandoned probably 25 years ago.
7.	Golden, Colo.	-	-	-	-	-	-	-	Abandoned (wodden cribbing).
8.	Greencastle, Ind.	-	-	1050	-	-	-	-	Abandoned in 1935.
9.	Harrisonberg, Virginia	Sand and Gravel	1½x1½	758	10	1	1.3	River	Vit. clay and G.I. gallery. Underground dam.
10.	Honolulu, T. H.	Volcanic fissures	10x10	68 - 919	-	0.4-20	1	Rock fissures -	No sand or gravel; tunnels are located just below normal water table. Excellent Bio. & Chem. quality.

* Orig. installed 1805-87; 250' long, 4' wide x 5' high. Built of sandstone 15' below grade. Adjacent to stream with average discharge of 404 sec-ft. Nearest point to stream is 66'. Gallery discharges to sump collection well. In 1950 gallery extended 400' using 36" reinf. conc. open joint pipe with manholes. Top soil and silt 6-9', dry gravel 3-6'. Water table 12' below. Well points used for new installation. Water is excellent bac. and chem. quality.

TABLE I (Cont'd)
INFILTRATION GALLERY SURVEY DATA SUMMARY

NO.	CITY	GALLERY				YIELD		SOURCE OF RECHARGE	NOTES:
		AQUIFER MEDIA	CROSS SECT.	LENGTH	DEPTH BELOW SURFACE	FOR TOTAL LENGTH	PER 1000'		
	Unit	--	Ft.	Ft.	Ft.	MGD	MGD	--	
11.	Ironton, Ohio	-	-	-	-	-	-	-	Abandoned.
12.	Los Angeles, Calif.	Sand and Gravel	1 - 15	Approx. 1500	2 - 136	6.5 - 11.5	1	River	** (See footnote).
13.	Middleville, Mich.	-	-	-	-	-	-	-	Abandoned because of contamination.
14.	Nashville, Tenn.	-	-	-	-	-	-	-	Abandoned.
15.	Newark, Ohio	-	-	-	-	-	-	-	Abandoned in 1924.
16.	South Haven, Mich.	Sand & Clay lenses	0.5	90	-	1.25	14	Lake Mich.	Abandoned 1902 (3 horizontal wells). (Fines-impacted well screens)
17.	Ventura, Calif.	Sand	4x3	30	3 - 5.5	.3	10	Pac. O.	Filter Box.
18.	Zanesville, Ohio	-	-	-	-	-	-	-	Abandoned.

** Gross spreading area 800'x2000' for recharge of aquifer. There are twenty-three "up-side-down" 12" ID wells that rise close to the surface sand, effective size surface sand = 0.015 mm. Uniformity coef.= 3.8 disregarding boulders greater than 1.5". Direct operating cost =s scarifying soil twice per year + pumping from sump.

TABLE II

INFORMATION ON INFILTRATION GALLERIES DESCRIBED IN LITERATURE

NO.	CITY	GALLERY: AQUIFER MEDIA	GALLERY: CROSS SECT.	GALLERY: LENGTH	GALLERY: DEPTH BELOW SURFACE	YIELD	SOURCE OF RECHARGE	NOTES:	REF.
	Unit	-	Ft.	Ft.	Ft.	MGD	-		
1.	Amsterdam, Netherlands	Sand	-	-	-	-	Rainfall	41% of rainfall collected	(3)
2.	Brookline, Mass.	Gravel	-	-	-	3.9-4.8	Rainfall		(1)
3.	Brussels, Belgium	Sand	-	-	-	5.35	Rainfall	29.4% rainfall coll.(cultivated)	(1)
4.	Brussels, Belgium	Sand	-	-	-	1.68	Rainfall	37% rainfall coll. (forrested)	(1)
5.	Crystal City, Mo.	Sand	.67 Dia	65	20	1.3	Miss.Riv.	Horizontal well	(3)
6.	Denver, Colo.	Sand	-	-	-	-	-	Wooden cribbing	(3)
7.	Denver, Colo.	Sand	2½x2½ 2½ Dia.	5280 5280	14-22 14-22	3 - 3.28	Platte River	Timber crib and perf. pipe. Velocity of inflow = $0.00004\sqrt{H}$	(1)
8.	Des Moines, Iowa	Coarse sands	1½x1-2/3 4 Dia.	8480	-	Max. 14	Racoon Riv.Val.	Manholes 600' apart. Recharge flooding.	(1)
9.	Frankfurt, Germany	Sand	-	-	43	-	Maine River	River water mech. filtered, spread and collected in galleries. Organic wastes thus purified.	(3)
10.	Leige, Belgium	Fissured chalk	-	-	-	3.68	Rainfall	18% of rainfall collected	(1)
11.	Munich, Germany	Gravel	3.3x5.8	-	-	-	Ground water		(3)

(1) Water Works Handbook, Flynn, Weston & Bogert, McGraw-Hill, 1927, pp. 260-265

(2) Long Island Sources, Board of Water Supply, City of New York, Vol. 1, pp. 283

(3) Public Water Supplies, Turneavre & Russell, John Wiley & Sons, 1940, pp. 294-299

TABLE II (Cont'd)

INFORMATION ON INFILTRATION GALLERIES DESCRIBED IN LITERATURE

NO.	CITY	GALLERY				YIELD	SOURCE OF RECHARGE	NOTES:	REF.
		AQUIFER MEDIA	CROSS SECT.	LENGTH	DEPTH BELOW SURFACE				
	Unit	-	Ft.	Ft.	Ft.	MGD	-		
12.	Naples, Italy	Gravel	-	2000	40 - 43	28	Ground Water	Open trench construction	(3)
13.	New York, N. Y.	Sand	1.5 - 3.0	12,600 15,200	10 - .5	12.6 - 15.2	Rainfall & Ground Water	Manholes each 250'. First cost 2 x well system but total operation cost less.	(2)
14.	Rennes, France	Decomposed granite	-	-	-	6.3	Rainfall	29.5% of rainfall collected	(1)
15.	Santa Barbara, California	Sandstone & shale	.67 Dia.	2000	-	.5 - 1	Rainfall to Underground reservoir	Used during dry summer. 45 MG storage reservoir controlled by valve	(1)

(1) Water Works Handbook, Flynn, Weston & Bogert, McGraw-Hill, 1927, pp. 260-265

(2) Long Island Sources, Board of Water Supply, City of New York, Vol. I, pp. 283

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OCTOBER:[b] 290(all Divs), 291(ST)[a], 292(EM)[a], 293(ST)[a], 294(PO)[a], 295(HY)[a], 296(EM)[a], 297(HY)[a], 298(ST)[a], 299(EM)[a], 300(EM)[a], 301(SA)[a], 302(SA)[a], 303(SA)[a], 304(CO)[a], 305(SU)[a], 306(ST)[a], 307(SA)[a], 308(PO)[a], 309(SA)[a], 310(SA)[a], 311(SM)[a], 312(SA)[a], 313(ST)[a], 314(SA)[a], 315(SM)[a], 316(AT), 317(AT), 318(WW), 319(IR), 320(HW).

NOVEMBER: 321(ST), 322(ST), 323(SM), 324(SM), 325(SM), 326(SM), 327(SM), 328(SM), 329(HW), 330(EM)[a], 331(EM)[a], 332(EM)[a], 333(EM)[c], 334(EM), 335(SA), 336(SA), 337(SA), 338(SA), 339(SA), 340(SA), 341(SA), 342(CO), 343(ST), 344(ST), 345(ST), 346(IR), 347(IR), 348(CO), 349(ST), 350(HW), 351(HW), 352(SA), 353(SU), 354(HY), 355(PO), 356(CO), 357(HW), 358(HY).

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a. Presented at the New York (N.Y.) Convention of the Society in October, 1953.
b. Beginning with "Proceedings-Separate No. 290," published in October, 1953, an automatic distribution of papers was inaugurated, as outlined in "Civil Engineering," June, 1953, page 66.
c. Discussion of several papers, grouped by Divisions.
d. Presented at the Atlanta (Ga.) Convention of the Society in February, 1954.
e. Presented at the Atlantic City (N.J.) Convention in June, 1954.

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